12Oct23

Thursday, October 12, 2023 6:02 PM

Todays class

1. What is steady-state ?....
2. How to obtain steady-state – models ... Space vectors
3. Analysis of IM in steady state ...
4. V/f control or Scalar control
5. Why do we need V/f control

$V \propto \phi . f$

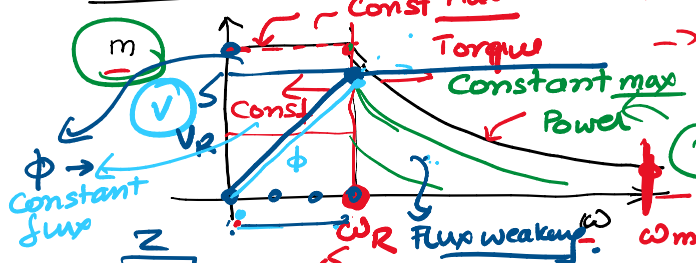
$m \propto \phi i_a$.

Revision DC

Speed – torque curve

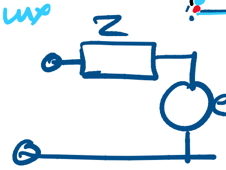
→ Steady-state

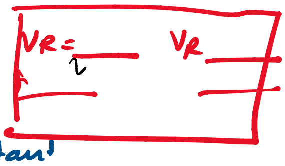
Rated ⟺ Continous maximum operating



$P = m . \omega$.

ω_{max} ← mechanical-limits Stal



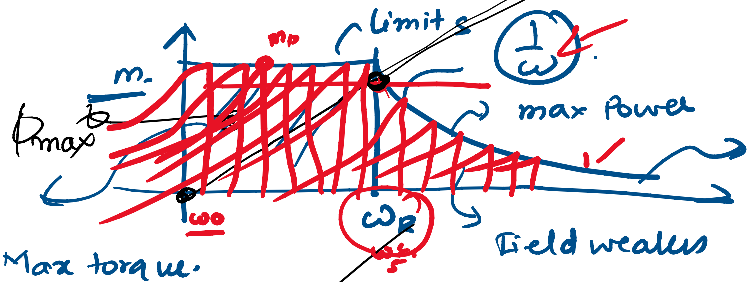


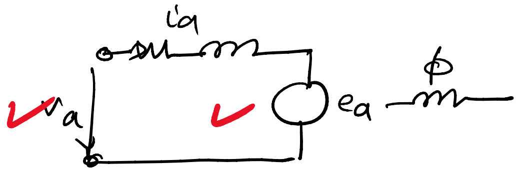
$e_a \propto \omega \phi$

$m_e = Const = K . I_a . \phi$ SE

Flux constant

$e_a \to V_R = Const = K . \phi . \omega$





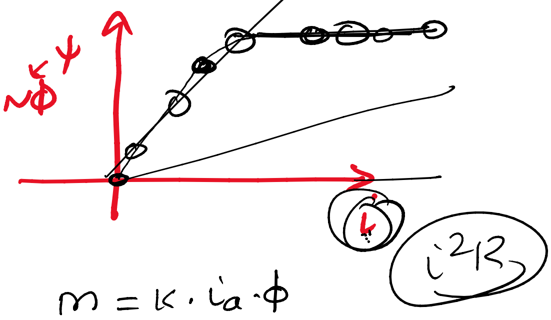
$V \propto \phi \omega$

$\phi \propto \frac{1}{\omega}$

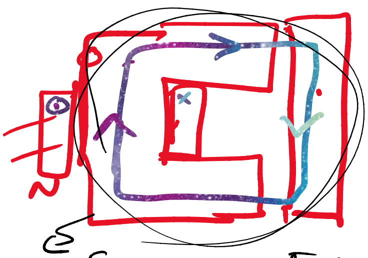
$e_a = (K) \phi . \omega$

back-emf ⟹ $V = \frac{d\psi}{dt}$ $\frac{1}{T} = f$

$\psi = N\phi$



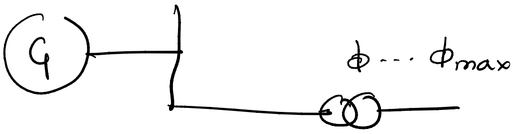
$m = K . i_a . \phi$

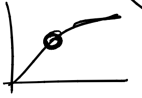


US – 110V

$f_{US} = 60Hz$

$\phi_{umax} = \frac{110}{60}$





$\phi_{max} = \frac{230}{50Hz}$

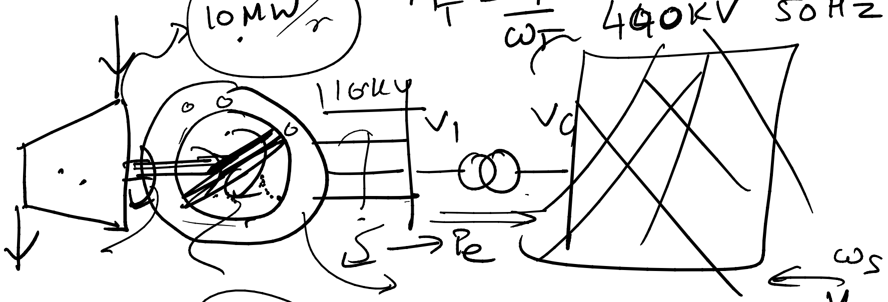
$= \frac{230}{50}$ ↑

$V \propto \frac{d\psi}{dt}$ $\psi = N\phi$ $\frac{1}{dt} \propto f$ $V \propto \phi . f$

P $P = M\omega$

$P \qquad P = M\omega$

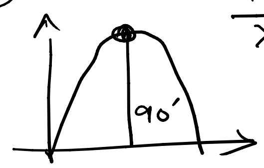
$10MW/r \qquad M_T = \frac{P_T}{\omega_T}$ 400KV 50Hz

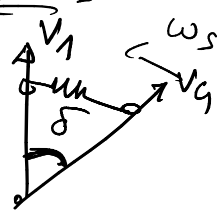


$2\pi \cdot \frac{d\omega}{dt} = P_T - P_e$

M_T 50Hz $P_e = \frac{V_1 \cdot V_G}{X_G} \cdot \sin\delta$

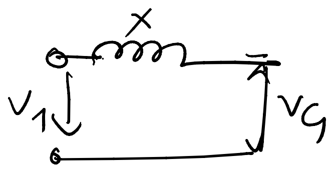
$M_T \cdot \omega_T \qquad \omega_T \to \omega_s$





$S = \underline{V}^* \cdot \underline{I}$

$P = Re\{S\} \qquad Q = Im\{S\}.$

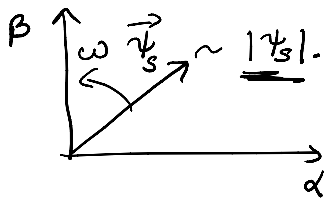


$\underline{I} = \frac{\underline{V_1} - \underline{V_G}}{X}$

Steady-state

$x \to V, I, \psi \ldots$

Space vector



$\vec{\psi_s} \sim |\psi_s| \cdot e^{j\omega_s t}$

$\frac{d|x|}{dt} = 0$

$\frac{d\vec{\psi_s}}{dt} = \frac{d\,|\psi_s|\,e^{j\omega_s t}}{dt} = \underbrace{\frac{d|\psi_s|}{dt}}_{=0.} \cdot e^{j\omega_s t} + j\omega_s (e^{j\omega_s t} \cdot |\psi_s|)$

$\frac{d\vec{\psi_s}}{dt} \xrightarrow{\text{Steady state}} j\underline{\omega_s}\,\underline{\psi_s}$

Space vector IM ...

$\vec{v_s} = \vec{i_s} \cdot r_s + \frac{d\vec{\psi_s}}{d\tau}$

$\vec{v_r} = r_r \cdot \vec{i_r} + \frac{d\vec{\psi_r}}{d\tau} - j\omega\vec{\psi_r}$

$\vec{\psi_s} = l_s \vec{i_s} + l_m \vec{i_r}$

$\vec{\psi_r} = l_m \vec{i_s} + l_r \vec{i_r}$

$$\vec{\psi}_r = l_h \vec{i}_s + l_r \vec{i}_r$$

$$l_s = (1+\sigma_s) l_h \quad l_r = (1+\sigma_r) l_h$$

$$\sigma = 1 - \frac{l_h^2}{l_s \cdot l_r} = 1 - \frac{1}{(1+\sigma_s)} \cdot \frac{1}{(1+\sigma_r)}$$

DC. $T_m = \frac{J \Omega_0}{M_B}$ (s)

$$m_e = \vec{\psi}_s \times \vec{i}_s$$

$$J.\frac{d\Omega}{dt} = M_e - M_L \rightarrow \frac{J}{M_B}.\frac{d\Omega}{dt} = \frac{M_e}{M_B}.$$

$$\tau_m \frac{d\omega}{dt} = m_e - m_L \qquad \frac{J}{M_B}.\frac{d(\Omega/\omega_B)\cdot\omega_B}{\frac{d(\omega_B \cdot dt)}{\omega_B}} = \frac{J\omega_B}{M_B}\frac{d\omega}{d\tau}$$

$$\tau = \omega_B \cdot t$$

$$d\tau = \omega_B \cdot dt$$

$$dt = \frac{d\tau}{\omega_B}$$

τ_m ?

$$\vec{\psi}_r, \vec{i}_s$$

$$\vec{\psi}_s = k_r \cdot \vec{\psi}_r + \sigma l_s \cdot \vec{i}_s$$

$$\vec{v}_s = r_s \vec{i}_s + j\omega_s \sigma l_s \cdot \vec{i}_s +$$

$$\vec{v}_s = r_s \vec{i}_s + \frac{d\psi_s}{d\tau}$$

$$\vec{v}_r = r_r \cdot \vec{i}_r + \frac{d\psi_r}{d\tau} - j\omega \vec{\psi}_r$$

$$\vec{\psi}_s = l_s \cdot \vec{i}_s + l_h \vec{i}_r$$

$$\vec{\psi}_r = l_h \vec{i}_s + l_r \cdot \vec{i}_r$$

Steady state

$$\vec{v}_s = r_s \cdot \vec{i}_s + j\omega_s \cdot \vec{\psi}_s$$

$$\vec{v}_r = r_r \cdot \vec{i}_s - j\omega \vec{\psi}_r + j\omega_s \cdot \vec{\psi}_r$$

$$= r_r \cdot \vec{i}_s + j(\omega_s - \omega) \cdot \vec{\psi}_r$$

$$\omega_r = \omega_s - \omega$$

$$s = \frac{\omega_s - \omega}{\omega_s}$$

$$\therefore \omega_s - \omega = s\omega_s$$

$$\vec{v}_r = r_r \cdot \vec{i}_r + js \cdot \omega_s \vec{\psi}_r$$

$$\frac{\vec{v}_r}{s} = \frac{r_r}{s} \cdot \vec{i}_r + j\omega_s \vec{\psi}_r$$

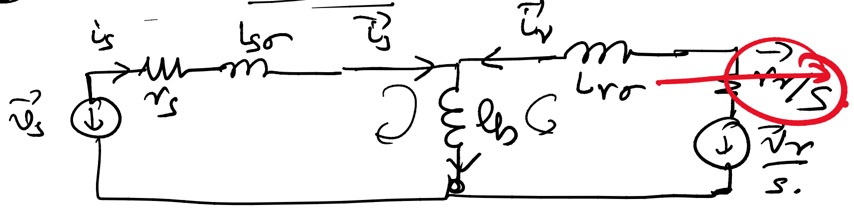
$$\vec{v}_s = r_s \cdot \vec{i}_s + j\omega_s \left[l_s \cdot \vec{i}_s + l_h \cdot \vec{i}_r \right]$$

$$l_s = l_{s\sigma} + l_h$$

$$\vec{v}_s = r_s \cdot \vec{i}_s + j\omega_s \left[l_s \cdot \vec{i}_s + l_h \cdot \vec{i}_r \right] \qquad l_s = l_{s\sigma} + l_h$$

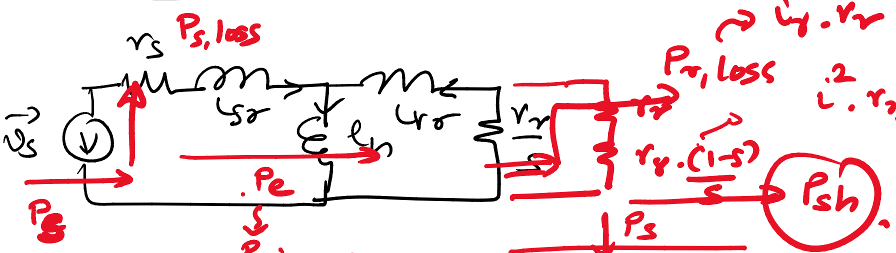
$$\vec{v}_s = r_s \vec{i}_s + j\omega_s l_s \cdot \vec{i}_s + j\omega_s l_h \cdot \vec{i}_r = r_s \cdot \vec{i}_s + j\omega_s l_{s\sigma} \cdot \vec{i}_s + j\omega_s l_h (\vec{i}_s + \vec{i}_r)$$

$$\frac{\vec{v}_r}{s} = \frac{r_r}{s} \cdot \vec{i}_r + j\omega_s \left[l_h \cdot \vec{i}_s + l_r \cdot \vec{i}_r \right]$$



$i_r^2 \cdot \frac{r_r}{s}$

Sq. IM. $\vec{v}_r \to 0$.

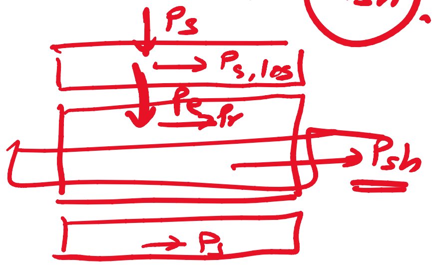


$i_r^2 \cdot r_r$

$i^2 \cdot \frac{r_r(1-s)}{s}$

$$m_{sh} = \frac{P_{sh}}{\omega} = \frac{P_e(1-s)}{\omega_s(1-s)} = m_e = \frac{P_e}{\omega_s}.$$

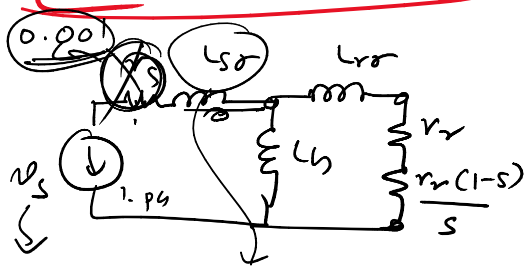
$$P_e = i_r^2 \cdot \frac{r_r}{s}$$

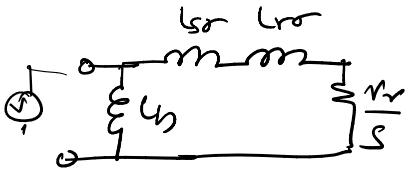


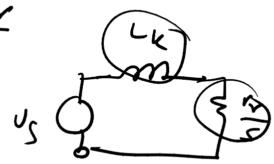
$P_e \;:\; P_{r,loss} \;:\; P_{sh}$

$$i_r^2 \cdot \frac{r_r}{s} \;:\; i_r^2 \cdot r_r \;:\; i_r^2 \cdot \frac{r_r(1-s)}{s}$$

$$\boxed{1 \;:\; s \;:\; 1-s}$$







$$(\omega l_k)^2 = \left(\frac{r_r}{s}\right)^2$$

$$\therefore S_p = S = \pm \frac{r_r}{\omega l_k}$$

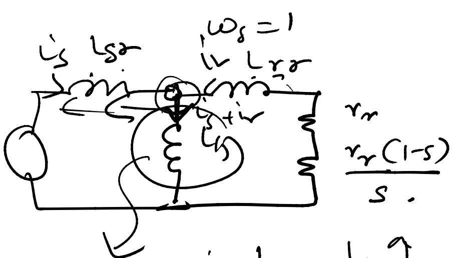
1. p.u

$\omega_s \cdot l_{s\sigma}$

$i_r^2 \cdot r_r$ – $P_{r,loss}$

$$\boxed{P_e = i_r^2 \cdot \frac{r_r}{s}}$$

$i_r^2 \cdot \frac{(1-s)}{s}$ – P_{sh}.



$i_m \downarrow \quad l_h \uparrow$